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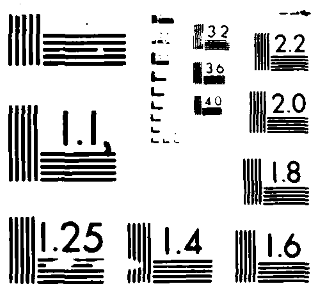

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TROPICAL CYCLONE SHIP AVOIDANCE PROGRAM (TCSAP) FOR THE WESTERN NORTH PACIFIC OCEAN

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The Tropical Cyclone Ship Avoidance Program (TCSAP), which is designed to replace the Pacific Fleet's tropical cyclone danger area avoidance instruction, is described. The Pacific Fleet danger area was tested on 1982 tropical cyclone forecasts, and summary results of these tests are given. The effect of a pending change in the Pacific Fleet allowance of 135 n mi to 120 n mi for error was simulated; summary results are presented. A constant peripheral risk danger area formulation was devised and compared to the present danger area. This constant peripheral risk danger area, based on the probability of 30 kt winds, is recommended as an alternate to the Pacific Fleet danger area.

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CONTENTS

1. INTRODUCTION

The U.S. Pacific Fleet uses a tropical cyclone danger area to mandate avoidance by its ships. Construction of this danger area begins with 30 kt wind radii drawn around the warning and 24-hr warning positions. The 24-hr radii are increased by an amount approximating the average 24-hr forecast error. The danger area is completed by enclosing the space between these wind areas with tangent lines. The allowance for average forecast error has been 135 n mi since the 1960s; however there has recently been a move at CINCPACFLT to decrease it to 120 n mi which more closely approximates the average error over the past decade or so (figure 1). The purpose of this study was to evaluate the danger area and investigate ways to improve it.

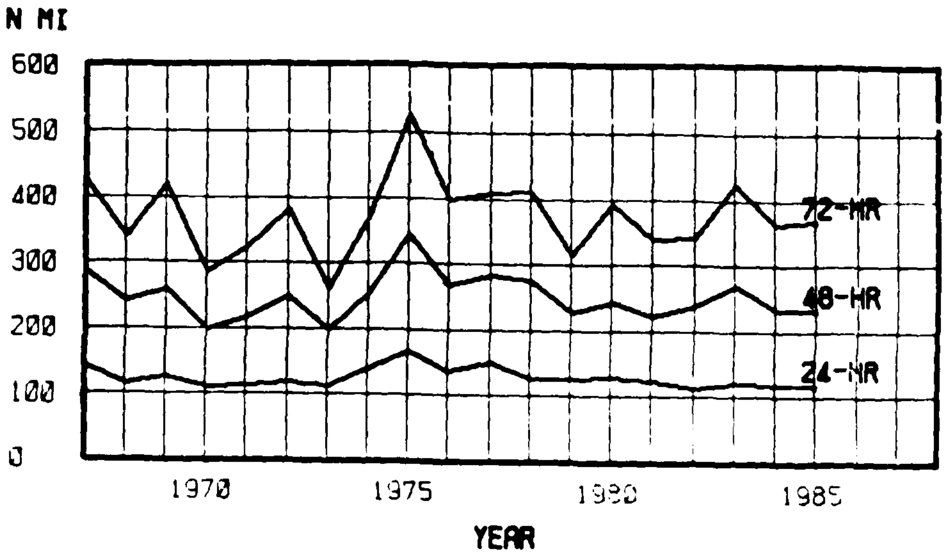


Figure 1. Annual JTWC forecast errors for all tropical cyclones in the western North Pacific region.

1.1 Purpose of the Danger Area

To evaluate the danger area one must first appreciate its purpose. The apparent objective is to keep ships out of 30 kt winds; however the underlying purpose is to keep ships out of dangerous areas where fully arisen seas up to 28 ft are possible. In fact 50-kt winds more closely represent actual danger to smaller ships; however, 30-kt winds and the accompanying seas reduce the maneuverability of ships and therefore the capability to avoid dangerous conditions. This is particularly true in the front quadrants of a tropical cyclone where, without positive evasive action, a ship will be overtaken by progressively worsening conditions. Additionally, in the right front quadrant (N.H.) the winds and seas also tend to force the vessel toward the cyclone's central core.

Because tropical cyclones rarely move equatorward in either hemisphere it has long been a favored evasion tactic to seek a position equatorward of the cyclone. This often requires crossing the forecast track ahead of the tropical cyclone. The fundamental problem in this maneuver, called "crossing the T", then becomes crossing far enough ahead to avoid the inhibiting winds and seas. Such seas in particular could slow progress to the point where the evasive maneuver becomes a rendezvous. Crossing ahead of the danger area minimizes this problem. Additionally, the danger area serves to signal a ship's captain when he has cut it too close and is in fact in jeopardy.

1.2 Strengths and Weaknesses of the Present Danger Area

The present danger area has three important advantages:

1. It is well understood.
2. It is simple and communicable.
3. It works.

Any replacement danger area that negates any of the above will have to prove its superiority with a strong case to be accepted. Proving superiority will have to be on the basis of the present system's assumed weaknesses:

1. It provides an unknown confidence.

2. It is inconsistent, overwarning in small error areas and underwarning in large error areas.

3. It does not reflect the natural bias in forecasts, errors to the right or left of the track are not equally likely in a given situation. The tropical cyclone wind probability model recognizes some such biases and allows for them, the present danger area does not.

4. It does not consider errors in the nowcast or forecast 30 kt wind area, the weakest part of a warning.

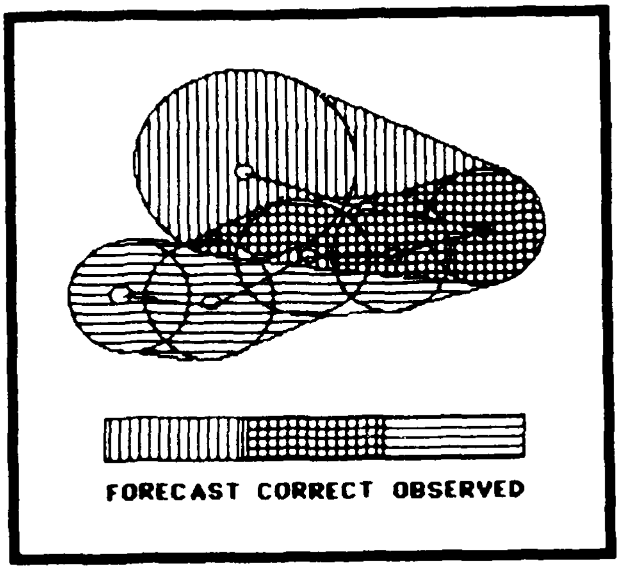
5. It may overwarn excessively.

2. EVALUATION OF THE DANGER AREA

2.1 Measures of Goodness

Figure 2 compares the present danger area schematically with the verifying area of 30 kt winds. The danger area was designed to allow for error in such a way that the area of 30 kt winds would almost always be included. This clearly requires some overwarning.

Figure 2. Schematic representation of danger area and verifying 30-kt wind areas (small circles).



The following three measures are designed to gauge how well the danger area performs.

1. Overwarning Rate (OR). This is defined as the ratio of the forecast area to the observed area in Figure 2. This parameter measures the over-warning included in the danger area. Generally we would like to see overwarning small since we are denying the use of the included ocean area to our ships. On the other hand, an overwarning rate of 1.0 makes no allowance for error either in the size or location of the 30-kt wind area. Notice that an OR of 1.0 does not necessarily imply that the forecast is 100% accurate (figure 2). Overwarning rates of 2-3 appear to be optimal. Like the rate of containment (below) the overwarning rate tends to be insensitive to changes on the danger area periphery being dominated by the "obvious" high threat center area.

2. Rate of Containment (RC). This is defined by the ratio of the "correct" area to the "observed" area of 30 kt winds in Figure 2. This parameter reflects the level of safety afforded by the danger area. This measure is biased because virtually any definition of danger area would include the "known" nowcast area of strong winds and that immediately ahead of the cyclone. This assures a high score (> 50-60%) yet does not allow for the unpredicted. Thus, in addition to this obvious area, an additional safety zone must be added. It should be noted that because ships move slowly, it is necessary that the danger area "lead" the tropical cyclone. That is, it not only needs to convey areas that are dangerous now but those that will be dangerous within 24 hours.

3. Peripheral Risk (PR). This is defined as the risk of encountering 30-kt winds at the periphery of the danger area. It is measured by the average 30-kt wind probability around the danger area border. With the present danger area this is a variable being greatest (typically about 0.5-0.6) for points just behind the cyclone (on the nowcast 30 kt isotach) and generally less (typically 0.10 to 0.15) at the leading edge of the danger area (figure 3). The apparent acceptability of moving in behind a TC may unwittingly expose vessels to a typhoon making a loop or U-turn which would rarely be correctly forecast. The risk at the leading edge depends on the forward speed of the cyclone, its size and intensity both

nowcast and forecast, and its forecast difficulty class. This is the most relevant measure of goodness since it is sensitive to the placement of danger area edges.

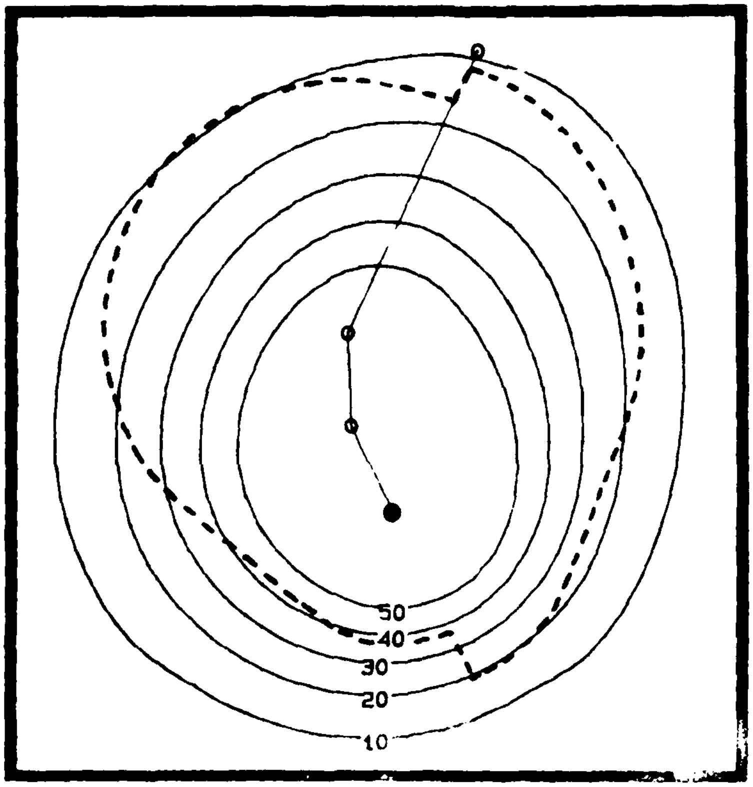


Figure 3. Depiction of an example of the CINCPACFLT danger area compared to 30-kt wind probability contours. The average peripheral risk of 30-kt winds is about 21% ranging from a low of 9% (top left) to a high of 43% (lower left of center).

2.2 Evaluation

JTWC forecasts for 1982 were reduced to machine readable records. An algorithm was developed to test whether a point was inside an area defined either as the CINCPACFLT danger area or a series of verifying 30-kt wind areas joined in sequence as shown in Figure 2. An MxN grid with 1° spacing was set up which included both the danger area and the verifying area of 30-kt isotachs. For each grid point the following were determined:

a. Is this point within the danger area?

b. Is this a point within the verifying isotach sequence?

c. Is this point within both a. and b. above?

d. What is the 24-hr elapsed time 30-kt wind probability?

A test sample of forecasts was selected for each of 3 difficulty classes (I = easy, II = average and III = difficult) so that no two forecasts were used together if they were less than 30 hours apart in time of issue. This was done to increase independence within the samples. Averages of overwarning rate (OR), rate of containment (RC) and the danger area peripheral risk (PR) were computed for the forecasts in the samples. These values are shown in Table 1 for class I, II and III forecasts.

Table 1. Summary of evaluation of a sample of danger area forecasts (see text for abbreviations).

CLASS	# FCSTS	CYCLONES	AVG ERROR (N MI)	OR	RC(%)	PR(%)
I	61	16	110	2.4	95.5	38
II	65	22	107	3.3	91.7	25
III	56	22	136	2.6	91.6	30

To interpret the results of Table 1, one must carefully consider the prevailing circumstances associated with each class of forecast. Class I is dominated by tropical cyclones in low latitudes with the average being a typhoon intensifying and growing larger. Since there is typically a 6-hr lag in recognizing size changes (as they show up in synoptic reports), these cyclones are typically understated in size in both the nowcast and the forecast. This tends toward a low overwarning rate but this tendency is compensated for by the "overall average" forecast error (135 n mi) being an excessive allowance for these easy forecast cyclones. The net is a near average overwarning rate. Because position errors are small, the entire verifying 30-kt wind area was contained within the danger area 77% of the time resulting in a very high (95.5%) rate of containment. This bias is on the safe side, the 135 n mi safety margin overwarns, but it is working. However, notice that the small size of the class I danger area results in the highest risk of 30 kt winds at the periphery (38%). The peripheral risk with the danger area varies widely from case to case. The range in this sample was 17 to 57%.

Class II tropical cyclones are a mixed group including formative storms and mature storms near recurvature. The 135 n mi allowance for error makes up a relatively large part of the danger area and there is no compensating underforecast

of size since size forecasts are best for this group. For these reasons overwarning rates are largest. Actual errors are usually larger and consequently RC is somewhat less than average. The risk of 30 kt winds on the periphery is somewhat below average at 25%. The range of peripheral risk around individual danger areas was 7 to 46%.

Class III tropical cyclones are typically post recurvature. They tend to be large and fast moving with both factors contributing to the large size of the danger area. As a consequence, the allowance for error makes up a relatively small part of the danger area. For this reason overwarning is below average. The largest component of forecast error is speed, meaning that when the danger area fails it typically has a small nose of verifying 30-kt winds protruding from the leading edge of the danger area. This class had only 57% of the verifying 30 kt wind areas fully contained in the respective danger areas, yet the RC was a very reasonable 91.6%. This means that the remaining 43% averaged only 20% of the 30-kt wind area falling outside of the danger area. Actually only two of those had as much as half their 30-kt winds outside the danger area. The peripherial risk of 30-kt winds is about average at 30% ranging from 13 to 61% in individual cases.

2.3 Summary of Evaluation

Perceived weaknesses in the present danger area were listed as presuppositions in section 1.2. It is now possible to either confirm or negate most of those assertions on the basis of evidence. The following will list the assertions and cite relevant evidence where applicable.

1. The danger area provides an unknown confidence. Since we now know that if we enter the danger area the likeli-

hood of encountering 30-kt winds is highly variable depending on sector entered, forecast difficulty class, forecast size and the statistics of size verification, this is a fair criticism.

2. The danger area is inconsistent, overwarning in small error areas and underwarning in large error areas. Small error areas are those associated with class I forecasts (generally low latitudes) while large error areas are those associated with class III forecasts (typically mid-latitudes). This weakness was not confirmed, and the degree of consistency shown in the test sample is surprising. The portion of over or underwarning attributed to track error was properly assessed, but the possiblity of compensating size/strength errors was not considered. It is true that the risk on the periphery is inconsistent, but it was anticipated that this risk would be lowest for class I forecasts and higher for classes II and III. What was found was, in fact, just the opposite.

3. It does not reflect the natural bias in forecasts. Errors to the right or left of the track are not equally likely in a given situation. The tropical cyclone wind probability model recognizes some such biases and allows for them, the present danger area does not. This was not tested; however, it is a factual statement not contradicted by the test results.

4. The danger area does not consider errors in the 30-kt wind area, the weakest part of a forecast. This was confirmed and, in part, the biased 30 kt wind radii forecasts compensate for other deficiencies. This is an extremely important aspect of the "allowance-for-error" problem and an aspect which will be addressed directly in the development of a new danger area formulation.

5. It may overwarn excessively. We now know what the distribution of overwarning rates is like; however, the acceptability of these (or any other) rates is a fleet policy matter.

3. DEVELOPMENT OF NEW DANGER AREA

A particular 24-hr 30-kt wind probability contour would be an ideal delimiter of a danger area since it would standardize the peripheral risk of 30-kt winds in all cases and would allow for errors in both position and wind radii. Selection of this contour and a method to simply describe it for shipboard plotting remains to be solved.

Using 135 n mi allowance for error the equivalent contours to the present danger area are 38%, 25% and 30% for class I, II and III forecasts respectively (Table 1). The impact of changing to 120 n mi for error allowance is to increase the equivalent wind probability. This is because higher wind probabilities are found toward the forecast track. The impact is about the same on forecasts of all classes. The new equivalent contour values are about 42%, 29%, and 34% respectively as shown in Table 2.

Table 2. Same as Table 1 except the definition of danger area changed by allowing 120 n mi for error vs 135 n mi, and the unaffected average forecast error column is omitted.

CLASS	#FCSTS	CYCLONES	OR	RC(%)	WP(%)
I	61	16	2.2	94.6	42
II	65	22	2.9	90.5	29
III	56	22	2.3	90.5	34

The change from 135 to 120 n mi allowance for error causes a predictable decrease in both overwarning rate and rate of containment and an increase in the peripheral risk factor.

In selecting a universal delimiter it is unreasonable to use a mean because that may result in unacceptable reduction in the safety factor afforded presently for class II. Rather we are forced either to have class dependent delimiters or to adopt a single delimiter of RC = 29, 34, or 42%. On the grounds that a high risk of encountering 30 kt-winds is just as undesirable for statistically good forecasts as for statistically bad forecasts, the single delimiter option is preferred. Since it is regarded as better to err on the conservative side the value of 29% is preferred. On the question of whether to use 29% or round it to 30%, the accuracy of wind probabilities does not justify the distinction and the convenience of remembering a 30% probability of 30-kt winds is somewhat appealing.

If the danger area is to be displayed using computer graphics it is elementary to draw the 30%, 24 hour 30 kt wind probability contour as the danger area. However, for shipboard applications it is better to provide for construction using circles and straight lines which is well within the capability of all navigation personnel. To include this the JTWC warning could be augmented to provide the appropriate simplified area description.

Figures 4, 5 and 6 depict examples of the present danger area and the 30% peripheral risk contour for class I, II and III forecasts for comparison.

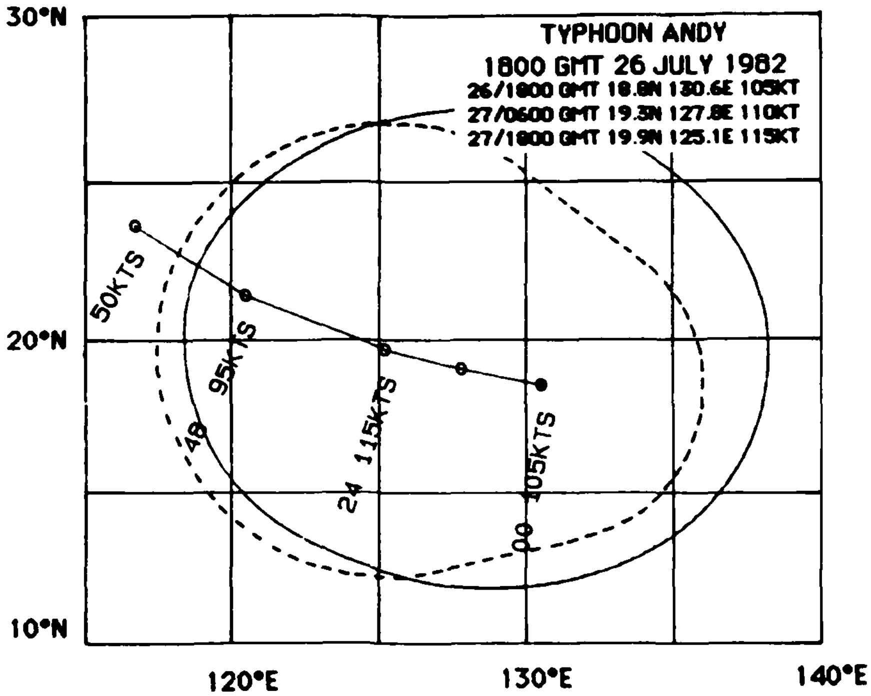


Figure 4. Typhoon Andy in the Philippine Sea, July 1982. Solid circle is nowcast position (1800 GMT 20 July); open circles are 12, 24, 48 and 72 hr forecasts. Large area enclosed by heavy dashed line is current CINCPACFLT danger area. Area enclosed by solid curve is contour of 30% probability of 30 kt winds within 24 hours. This is a class I forecast.

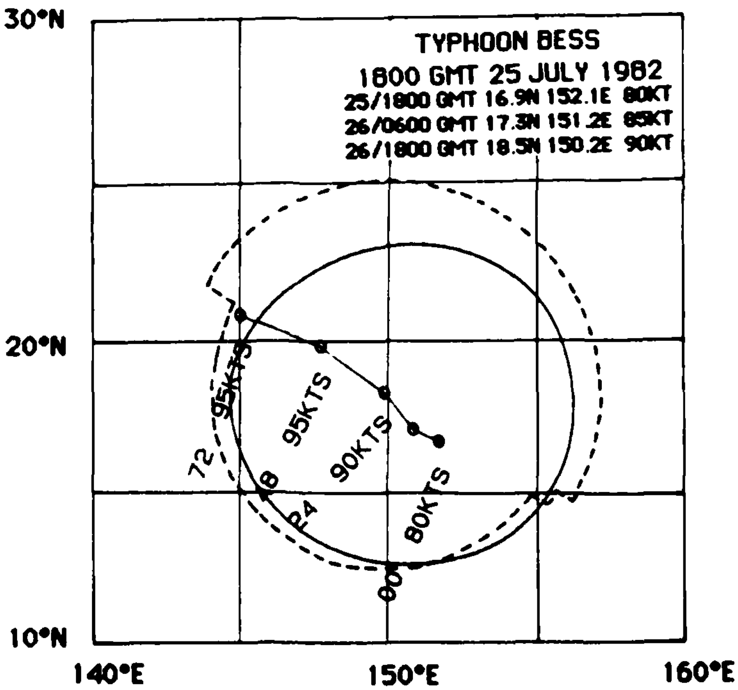


Figure 5. Typhoon Bess in the mid-Pacific east of Guam, July 1982. For explanation of lines and symbols, see Fig. 4. This is a class II forecast.

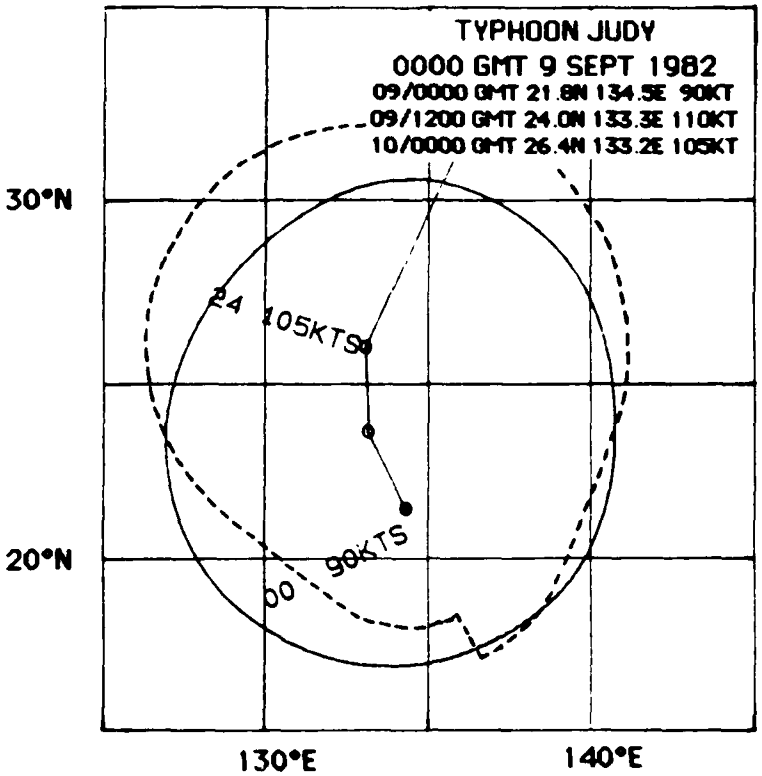


Figure 6. Typhoon Judy east of the Luzon Straits, September 1982. For explanation of lines and symbols, see Fig. 4. This is a class III forecast.

Table 3 summarizes the performance of the 30% contour danger area on the same development data.

Table 3. Same as Table 2 except the danger area is defined as the contour of 30% probablity of 30-kt winds.

CLASS	#FCSTS	CYCLONES	OR	RC(%)	WP(%)
I	61	16	3.1	96.8	30
II	65	22	2.8	87.4	30
III	56	22	2.8	89.7	30

What has been accomplished is a standardization of the peripheral risk. The effect of this is to generally increase the size of the danger area around the nowcast, decrease

it somewhat around the 24-hr forecast, and skew the remainder slightly to the right. In effect we are trading off some allowance for 24-hr forecast error for nowcast error particularly in the 30-kt wind radius. We are also acknowledging a preference for certain types of errors depending on forecast difficulty class. For example, in class I the most serious source of errors is in the 30-kt wind radius. In class III the most serious error is in the forward speed. The rate of containment for classes II and III was decreased slightly by assuming more risk at 24 hours and less at forecast time.

The derived constant peripheral risk danger area does not compromise the desirable features of the danger area and yet is a more realistic treatment of the risk of a close encounter with a tropical cyclone.

4. RECOMMENDATION

It is recommended that the 30% (elapsed time) 30-kt wind probability contour be adopted as an alternate to the Pacific Fleet danger area. This change would require the danger area be computed and specified by Naval message (e.g., it could be a part of the current STRIKP message). Its description can be adequately portrayed by two circles with tangent lines. This has the added advantage of being spelled out explicitly in the message rather than requiring the user to hunt the information pieces from four or five different lines buried within a very "busy" warning message.

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